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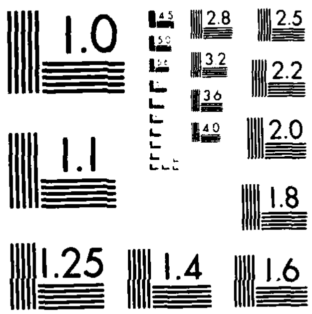

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INSPECTION DATA FOR SPARK-IGNITION ENGINES FROM AIR FORCE NONTACTICAL VEHICLES (MEEP Project H79-1C, Synthetic Oils)

INTERIM REPORT
AFLRL No. 163

VOLUME I – TECHNICAL REPORT

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Contract No. DAAK70-82-C-0001

January 1983

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
AFLRL No. 163

2. GOVT ACCESSION NO

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
INSPECTION DATA FOR SPARK IGNITION ENGINES FROM AIR FORCE NONTACTICAL VEHICLES (MEEP PROJECT H79-1C, SYNTHETIC OILS)
Volume I - Technical Report

5. TYPE OF REPORT & PERIOD COVERED
Interim Report
September 1981-October 1982

6. PERFORMING ORG. REPORT NUMBER
SwRI-6800-121

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER(s)
DAAK70-82-C-0001

9. PERFORMING ORGANIZATION NAME AND ADDRESSES
U.S. Army Fuels and Lubricants Research Laboratory, Southwest Research Institute, P.O. Drawer 28510, San Antonio, TX 78284

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Belvoir Research and Development Center
ATTN: STRBE-VF
Fort Belvoir, VA 22060

12. REPORT DATE
January 1983

13. NUMBER OF PAGES
28

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
A limited number of copies of Volume II, Appendices have been printed. Microfilm copies of both volumes are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22314

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Synthetic lubricants
Multiviscosity
Additives
Alkalinity
Particulates

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Many DOD vehicles are operated under short-trip, "stop and go" conditions. Since this type of operation imposes severe requirements on the engine oil and because poor performances and failure in the engine oil increase operation and maintenance costs, the decision was made to test synthetic lubricants as a possible solution to the problem. Today's energy shortage, rising labor and material cost, and smaller budgets require exploration of

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20. ABSTRACT (Cont'd)

potential methods of cost reductions in operation of government vehicles. This MEEP project was requested by the Triservices through the Joint Deputies for Laboratory Committee (JDLC). Of approximately 450 general-purpose vehicles selected by 11 Air Force installations for this program, 29 of the vehicles were chosen for engine inspection at USAFLRL, San Antonio, TX. These 29 engines were disassembled by AFLRL personnel and inspected in accordance with CRC rating methods. Wear measurements were made of selected parts, and photographs were taken of representative parts from each engine. For various reasons the three engines from Sondrestrom Air Force Base were eliminated from the test at this point and are not included in this report. The number of engines was thus reduced to 26. A comparison was also made between the lubricants used in the test by utilizing the oil analyses data provided by the Technical Service Center, Joint Oil Analysis Program Laboratory in Pensacola, FL and copies of the individual maintenance records provided by each installation. Based solely on the results of the engine tear-down inspections and in consideration of the data developed from oil analyses and maintenance records, synthetic lubricants can be successfully used in spark ignition engines. Statistical studies revealed no significant differences could be determined which would clearly indicate if the use of any one test oil would be more advantageous than the use of any of the other test lubricants. Final conclusions, of course, reside with the Warner Robins Air Logistics Center where coordination of the compilation of a report covering all aspects of the program will be made.

FOREWORD/ACKNOWLEDGMENTS

This report was prepared by the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) located at Southwest Research Institute, San Antonio, TX, under Contract No. DAAK70-82-C-0001. It presents the work done by AFLRL personnel for the period September 1981 through October 1982. This work was performed as part of MEEP Project H-79-1C, Synthetic Oils initiated by the U.S. Air Force at Warner Robins Air Logistics Center (AFLC), Robins Air Force Base, GA in response to a request by the Triservices through the Joint Deputies for Laboratory Committee (JDLC). The Project monitor for the Air Force was Mr. C.H. Coffey, Warner Robins Air Force Base. The Project Monitor and Contracting Officer's Representative for the Army was Mr. F.W. Schaekel, Belvoir Research and Development Center, STRBE-VF, Ft. Belvoir, VA.

The authors acknowledge with appreciation the cooperation and immediate response by MEEP and Air Force maintenance personnel, without which this report could not have been successfully concluded. Also appreciated was the help and support of Mr. Sidney J. Lestz, USAFLRL.

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I. INTRODUCTION

A multivehicle fleet test utilizing U.S. Air Force general-purpose vehicles was organized and conducted from approximately March 1980 through June 1981 at the request of the Triservices through the Joint Deputies for Laboratory Committee (JDLC).(1)* The project was conducted under the direction of the Management and Equipment Evaluation Program (MEEP) Section, Materiel Analysis Branch, Warner Robins Air Logistics Center (AFLC), Warner Robins Air Force Base, GA and was designated as MEEP Project H 79-1C, Synthetic Oils. The Project Manager, WR-ALC, was directed to coordinate with the U.S. Army to perform teardown inspections of 29 of the test engines at the conclusion of the test. This was done with the U.S. Army Belvoir Research and Development Center, Ft. Belvoir, VA which provided the funding, and designated the U.S. Army Fuels and Lubricants Research Laboratory (USAFLRL) located at Southwest Research Institute (SwRI), San Antonio, TX as the agency responsible for the after-test inspections of the 29 engines.

The objective of the test was to determine through accumulation of field data if use of synthetic engine oil would extend oil drain intervals, reduce oil filter changes, eliminate sludge buildup, prolong engine life, give advantages in fuel consumption, improve cold weather starting, and reduce operational cost. The synthetic oils chosen were of different manufacture and were assigned the color codes Yellow and Green. The baseline, or control oil was a mineral oil of normal procurement and stockage. This oil was color coded Blue.

II. DETAILS OF TEST

Test Procedures

Reference 1 includes guidelines for the selection and preparation of vehicles used in the test. Each designated U.S. Air Force Major Command (MAJCOM) was directed to select a minimum of 60 general-purpose, gasoline

* Underscored numbers in parentheses indicate references at the end of this report.

engine-powered vehicles. The vehicles were selected in groups of three and were matched as nearly as possible as to make, model, age, mileage, engines, general condition, and use. Within each set, one vehicle was operated with a mineral oil, and each of the other two vehicles was operated with a synthetic oil of different manufacture. One set of three vehicles was selected from each MAJCOM for after-test disassembly and inspection. Parameters for taking oil samples and changing oil and filters were established as well as procedures for sample analysis.

- Vehicles designated to use synthetic lubricants had oil samples taken and the crankcase oil and oil filter changed at the beginning of the test.
- These vehicles were operated for 500 miles or 50 hours and again had oil samples taken and the crankcase oil and oil filter changed to ensure purging of any mineral oil that may have remained in the crankcase.
- After this second oil and filter change, oil samples were taken from all involved vehicles each 2000 miles or 600 hours of operation.
- Oil samples were forwarded to Air Force personnel at the Joint Oil Analysis Program (JOAP) Laboratory in Pensacola, FL.
- Engine oil was changed as necessary by comparing laboratory findings with parameters developed by the Air Force Systems Command (AFSC).
- Oil filters were changed each 6000 miles or when the oil was changed, whichever occurred first.
- In case of engine failure, an additional oil sample was drawn and forwarded to the USAFLRL.(2)

Some of the engines did fail, and an investigation into the cause of each was done by AFLRL personnel. A final report, AFWAL-TR-81-4153 "Field Liaison in Support of Evaluation of Synthetic Lubricants in NonTactical Vehicles", published in February 1982(2), gives the details of each failure including the probable cause. According to the report, none of the engine failures was due to oil-related causes.

On completion of test, a portion of the vehicles operating on each test lubricant were designated for engine teardown inspections. Vehicle engines were removed and forwarded to the AFLRL where they were disassembled and evaluated for condition, wear and deposit formation. Table 1 identifies the vehicles selected for inspection.

Test Lubricants, Synthetic and Control

Six engine lubricants were used in testing the twenty-nine engines chosen for teardown inspections at USAFLRL. Four of the oils were MIL-L-46152 Qualified Products which met the requirements established in MIL-L-46152 "Military Specification, Lubricating Oil, Internal Combustion Engine, Administrative Service". The other two oils were certified to meet the MIL-L-46152 standards. Of the six lubricants, two were multiviscosity synthetic lubricants each manufactured by a different company. One of the lubricants was color coded Yellow, while the second synthetic lubricant was color coded Green. The other four oils were standard issue mineral oils and were color coded Blue. To differentiate one Blue oil from another of different manufacture, they were further designated as Blue(A), Blue(B), Blue(C), and Blue(D). Thus, comparisons are possible between mineral oils as well as a collective comparison against the synthetic lubricants used in the test.

As stated in Reference 1, sampling of new synthetic lubricants was not required to establish a baseline because this had already been done by the JOAP laboratory and the organization procuring the oil. Therefore, baseline data on the lubricants used in the synlube test were requested from the JOAP Laboratory in Pensacola, FL. These data were provided and form the basis for the values shown for the synthetic lubricants in Table 2, "Physical Properties of Test Lubricants". The values in the table pertaining to the Blue oils were determined by USAFLRL using approved ASTM methods.

TABLE 1. DESCRIPTION OF VEHICLES IDENTIFIED FOR TEARDOWN

MAJCOMS	Installation	Test Lubricant	Vehicle Reg. No.	Make & Type Vehicle	Engine & Disp.
	USAFA, CO	Green	79B5659	Ford Sedan, Compact	6 cyl, 200 CID
		Yellow	79B5660	Ford Sedan, Compact	6 cyl, 200 CID
		Blue(C)	79B5668	Ford Sedan, Compact	6 cyl, 200 CID
TAC	GAFB, CA	Green	79B2533	Dodge Panel Truck	V-8, 318 ICD
		Yellow	79B2534	Dodge Panel Truck	V-8, 318 CID
		Blue(C)	79B2539	Dodge Panel Truck	V-8, 318 CID
SAC	GFAFB, ND	Blue(B)	79B1735	Chevrolet Truck, Carryall	V-8, 350 CID
		Yellow	79B1734	Chevrolet Truck, Carryall	V-8, 350 CID
ADCOM	HAFB, NY	Green	78B5038	Plymouth, St. Wagon, Compact	6 cyl, 225 CID
		Yellow	78B5646	Ford, Truck, Stake body	6 cyl, 300 CID
ATC	LAFB, TX	Yellow	79B2270	Ford Truck, 1 1/2 T, 4x2	6 cyl, 300 CID
		Green	79B2271	Ford Truck, 1 1/2 T, 4x2	6 cyl, 300 CID
		Blue(A)	79B2272	Ford Truck, 1 1/2 T, 4x2	6 cyl, 300 CID
SAC	MAFB, ND	Green	79B1736	Chevrolet Truck, Carryall	V-8, 350 CID
		Blue(C)	79B1759	Chevrolet Truck, Carryall	V-8, 350 CID
TAC	MBAFB, SC	Green	79B5212	Plymouth Sedan	6 cyl, 225 CID
		Yellow	79B9187	Plymouth Sedan	6 cyl, 225 CID
		Blue(D)	79B9188	Plymouth Sedan	6 cyl, 225 CID
SAC	OAFB, NE	Green	78B4766	Chevrolet Truck, Delivery	6 cyl, 292 CID
		Blue(C)	78B4768	Chevrolet Truck, Delivery	6 cyl, 292 CID
ADCOM	PAFB, CO	Yellow	78B4571	Chevrolet Truck, Multistop, 7K#	6 cyl, 292 CID
		Green	78B4569	Chevrolet Truck, Multistop, 7K#	6 cyl, 292 CID
		Blue(C)	78B8831	Chevrolet Truck, Multistop, 7K#	6 cyl, 292 CID
ATC	RAFB, TX	Yellow	79B5719	Ford Sedan, Compact	4 cyl, 140 CID
		Blue(A)	79B5720	Ford Sedan, Compact	4 cyl, 140 CID
		Green	79B5721	Ford Sedan, Compact	4 cyl, 140 CID

TABLE 2. PHYSICAL PROPERTIES OF TEST LUBRICANTS

Lubricant Color Code / Lubricant Type	MIL-L-46152 Qualified*		Certified to meet MIL-L-46152 Specifications		MIL-L-46152 Qualified	
	Green Synthetic	Yellow Synthetic	Blue(A)a/ Mineral	Blue(B) Mineral	Blue(C) Mineral	Blue(D)b/ Mineral
Description:						
API Service Classification	SE/CC	SE/CC	SE/CC	SE/CC	SE/CC	SE/CC
Viscosity Classification	10W-30	10W-40	10W-30	10W-40	10W-30	10W-40
Properties*						
Kvis. @ 100°C, cSt	10.20	13.8	11.06	13.17	10.29	13.65
Kvis. @ 40°C, cSt	52.2	78.4	ND	ND	ND	ND
Viscosity Index	180	182	ND	ND	ND	ND
TAN	2.6	2.96	1.69	2.55	2.38	3.41
TBN	6.9	6.3	ND	ND	ND	ND
Flash Point, °C	204	232	ND	ND	ND	ND
Pour Point, °C	-48	-43	ND	ND	ND	ND

* - Data provided JOAP Laboratory by the company supplying the synthetic lubricants

ND - Not determined

a/ - Oil sample received at AFLRL was labeled as a 10W-40 grade oil. However, subsequent testing proved it to be a 10W-30 grade oil.

b/ - Oil sample received at AFLRL was labeled as a 10W-30 grade oil. However, subsequent testing proved it to be a 10W-40 grade oil.

III. RESULTS OF TEST

Lubricant performance was evaluated by two methods:

(1) analysis of the data provided by the JOAP laboratory, and

(2) after-test inspections of engines selected by each designated MAJCOM and the USAF Academy.

Used Oil Analyses

All the lubricants used in the 26 engines inspected at AFLRL appeared to have performed satisfactorily. Some oil distress occurred as shown by high viscosity values for some engines. Table 3 shows the average viscosity density product (VDP) for test oils used at each Air Force installation and identifies those oils that were outside the parameters establishing the acceptable range for each oil at a given temperature.(3) The TSC, JOAP determined the VDP for new test lubricants for each deg F for a range of ambient temperatures. These VDPs were labeled "True Values" which is the basis for the term's use in this report. Each True Value VDP was then multiplied by 0.25, and the result was added to and substracted from its respective True Value VDP to establish parameters for VDP acceptability. Appendix D, Volume II, shows the average for each wear metal, additive element, particulate content, and VDP of each test oil for each test engine. These averages were used to establish a mean and standard deviation for each of the data categories for each group of test oil, (i.e., Yellow, Green and Blue). A statistical analysis then established the range of predicted difference between the means for the test oils.

By comparing the means for each variable of one oil with the means for each respective variable of a second oil, it was determined that there were no statistical differences between the means for any variable listed except one. There was a statistical difference between the means for the variable, VDP, for the Blue and the Green lubricants. This does not mean that one oil is better than the other, only that the difference between VDPs for each oil at the beginning of the test was still present at the end of the test. Appendix E, Volume II, contains an explanation of the statistical tests used. Table 4 illustrates the True Value VDPs for each test oil at 74°F at

TABLE 3. COMPARISON OF TRUE VALUE (T.V.) VDP* (Baseline) WITH USED TEST OIL VDP

Installation	Blue Oil Code	New Oil VDP Temp, °F	New Oil VDP Low Limit	New Oil VDP TV	New Oil VDP High Limit	Used Oil Average VDP Temp, °F	Used Oil Average VDP VDP
USAF Academy	C	75	84	112	140	74.5	95.93
George AFB	C	74	87	116	145	73.5	154.04 a/
Grand Forks AFB	B	74	95	126	158	73.7	161.14 a/
Hancock AFB b/							
Lackland AFB	A	74	72	96	120	73.9	111.57
Minot AFB	C	73	89	119	132	73.2	130.28
Myrtle Beach AFB	D	74	76	101	126	74	98.85
Offutt AFB	C	74	87	116	145	74	124.92
Peterson AFB	C	74	87	116	145	73.8	112.67
Randolph AFB	A	75	76	101	126	74.5	121.83

*VDP = Viscosity Density Product (Centipoise x g/cm^3)
a/ = VDP value outside of range established by True Value ± 25 percent.
b/ = Hancock AFB did not ship any test engines that had used a Blue oil.

TABLE 3. COMPARISON OF TRUE VALUE (TV) VDP* (Baseline) WITH USED TEST OIL VDP (CONT'D)

	Yellow Oils						Green Oils					
	New Oil VDP				Used Oil Average VDP		New Oil VDP				Used Oil Average VDP	
Installation	Temp, °F	Low Limit	TV	High Limit	Temp, °F	VDP	Temp, °F	Low Limit	TV	High Limit	Temp, °F	VDP
USAF Academy	74	81	108	134	74	113.80	74	65	87	109	74.1	89.70
George AFB	73	83	110	138	73	154.14 a/	73	67	89	112	73.2	116.40 a/
Grand Forks AFB	73	83	110	138	73.5	175.60 a/	-+	-	-	-	-	-
Hancock AFB b/	75	79	105	131	74.8	102.00	74	65	87	109	73.5	92.17
Lackland AFB	73	83	110	138	73.5	101.60	74	65	87	109	73.8	93.00
Minot AFB	- b/	-	-	-	-	-	73	67	89	112	73.2	119.05 a/
Myrtle Beach AFB	74	81	108	134	74	108.22	74	65	87	109	73.5	96.68
Offutt AFB	- b/	-	-	-	-	-	74	65	87	109	73.8	113.08 a/
Peterson AFB	74	81	108	134	73.6	119.14	74	65	87	109	73.8	87.80
Randolph AFB	73	83	110	138	73.5	134.00	73	67	89	112	73.4	85.08

*VDP= Viscosity Density Product (Centipoise x g/cm^3)
a/ = VDP values outside of range established by the True Value ± 25 percent.
b/ = No test engines were received that had used Yellow oil during the test.
+No engine utilizing Green oil was shipped from Grand Forks AFB.

the beginning of the test and the average VDPs for each test oil at the end of the test at an average 74°F. Also shown is the average percent increase in VDP for each test oil.

TABLE 4. PERCENT INCREASE IN VDPs*

Color Code	Average True Value VDP Beginning of Test	Average VDP At End of Test	Average Percent Increase
Green	88	100	13.64
Blue(Avg.)	111	123	10.81
Yellow	109	126	15.60

*Average temperature for determining VDP before and after the field test was 74°F.

Unfortunately, total acid numbers (TANs) and total base numbers (TBNs) were not determined at JOAP laboratories. Oil alkalinity reserve capacity and other oil properties and conditions were shown in subjective terms as follows:

Oil alkalinity reserve capacity.......Good or bad

Oil dispersive properties.............Good, fair or poor

Particulate contaminants..............Light, medium or heavy

Coolant contamination.................Not present or present

These properties and conditions were determined by blotter tests and included in the oil analyses computer printouts from the JOAP laboratories. A summary of these oil properties and conditions is given in Table 5.

Reference 3 also gave the baseline data for additives for each of the test lubricants. The quantities given in the oil analysis computer printouts for used oil samples were averaged for each test lubricant. Table 6 compares the used oil sample additive quantity averages with the values shown in Reference 3. Calcium was not included in the computer printouts; therefore, no comparisons for that element could be made. It should also be noted that the value of 998 is the highest value in parts per million (ppm) that is

TABLE 5. LUBRICANT ANALYSIS DATA SUMMARY

Installation	Vehicle Number	Lubricant Code	Average VDP[a]	Average Particulate, mL of Solids	Particulate Range, mL of Solids	Total Particulate Contaminants[b]	Coolant Contamination In Oil	Alkalinity Reserve Capacity	Oil Dispersive Properties
USAF Academy	79B5659	Green	89.70	0.15	0.06-0.25	Medium	Not present	Good	Fair
	79B5660	Yellow	113.80	0.14	0.01-0.30	Med to hvy	Not present	Good	Fair
	79B5668	Blue (C)	95.93	0.07	0.05-0.10	Medium	Not present	Good	Good to fair
George AFB	79B2533	Green	116.40	0.11	0.01-0.20	Lt to med	Not present	Good	Fair
	79B2534	Yellow	154.14	0.08	0.01-0.40	Medium	Not present	Good	Fair
	79B2539	Blue (C)	146.83	0.19	0.01-0.57	Med to hvy	Not present	Bad	Fair
Grand Forks AFB	79B1734	Yellow	171.12	0.02	0.01-0.06	Lt	Present	Good	Fair
	79B1735	Blue (B)	161.14	0.08	0.01-0.40	Lt to med	Not present	Good	Good to fair
Hancock AFB	78B5038	Green	94.72	0.18	0.01-0.31	Medium	Not present	Good	Fair
	78B5646	Yellow	111.80	0.23	0.01-0.71	Medium	Not present	Good	Fair
Lackland AFB	79B2270	Yellow	101.60	0.13	0.01-0.20	Medium	Not present	Good	Fair
	79B2271	Green	93.00	0.22	0.18-0.32	Med to hvy	Not present	Good	Fair to poor
	79B2272	Blue (A)	111.57	0.15	0.08-0.25	Lt to med	Not present	Bad	Fair
Minot AFB	79B1736	Green	119.05	0.14	0.01-0.28	Medium	Not present	Good	Fair
	79B1759	Blue (C)	130.28	0.14	0.01-0.40	Medium	Not present	Good	Fair
Myrtle Beach, SC	79B5212	Green	96.68	0.15	0.01-0.22	Medium	Not present	Good	Fair
	78B9187	Yellow	108.22	0.25	0.06-0.60	Med to hvy	Not present	Good	Fair to poor
	78B9188	Blue (D)	98.85	0.11	0.02-0.30	Lt to med	Not present	Good	Good to fair
Offutt AFB	78B4766	Green	113.08	0.18	0.01-0.30	Med to hvy	Not present	Bad	Fair
	78B4768	Blue (C)	124.92	0.25	0.12-0.50	Med to hvy	Not present	Bad	Fair
Peterson AFB	78B4571	Yellow	119.14	0.32	0.15-0.60	Medium	Not present	Bad	Fair to poor
	78B4569	Green	87.80	0.13	0.06-0.17	Medium	Not present	Good	Good to fair
	78B8831	Blue (C)	112.67	0.23	0.10-0.30	Med to hvy	Not present	Good	Fair
Randolph AFB	79B5719	Yellow	134.00	0.04	0.01-0.08	Medium	Not present	Good	Fair
	79B5720	Blue (A)	121.83	0.06	0.02-0.10	Lt to med	Not present	Bad	Fair
	79B5721	Green	85.08	0.11	0.08-0.12	Lt to med	Not present	Good	Good

a/ = Viscosity Density Product (Centipoise x g/cm^3)
b/ = Light; Med = Medium; Hvy = Heavy

TABLE 6. AVERAGE ADDITIVE QUANTITIES FROM USED OIL SAMPLES COMPARED TO NEW OIL ADDITIVE QUANTITIES*

Additives	Blue A		Blue B		Blue C		Blue D		Yellow		Green	
(PPM)	New	Used	New	Used	New	Used	New	Used	New	Used	New	Used
B	1	5	0	61	184	86	0	2	11	33	3	20
Ba	0	8	0	7	3	81	80	65	118	123	998	985
Mg	8	69	538	350	532	685	450	433	15	124	538	694
Zn	469	770	740	956	941	985	844	958	998	991	663	903

* Information provided by the JOAP Laboratory, Pensacola, FL.

determined in oil analyses by the TSC, JOAP laboratories. The actual ppm for any given element may be much higher than the value 998 but measurement limitations prohibit the determination of the exact values. Overall this means that a significant part of oil analyses data essential to decision-making as to whether or not an engine is jeopardized may not be available.

After-Test Engine Inspections

Ratings for the 26 engines inspected by USAFLRL are contained in Appendix A, Volume II, "Engine Inspection Data-Ratings". Sludge ratings were not made for the two engines shipped from Hancock Air Force Base, New York because the parts normally rated for sludge deposits were not shipped with the engines.

The inspection results showed that Chevrolet engines, both the V-8, 350 CID and the six cylinder, 292 CID, appeared to have fared the worst according to the ratings. They appeared to have been particularly susceptible to lifter body wear and piston scuffing with all lubricants in the program. A comparison of these engines to the total test mileages driven shows that six of them were among the highest mileage engines in the test. However, the three 292 CID engines from Peterson AFB which were among the lowest in total test miles still showed abnormal wear to lifter bodies. Again, it should also be noted that the lifter and piston wear occurred whether a green, yellow or blue test lubricant was used. However, a study of the maintenance history of each of these engines reveals that normal maintenance procedures were followed for three of the four engines operated with Blue oils and one of the three engines operated with a Green lubricant. Two of the engines operated with Yellow lubricants had extensive maintenance problems for the test period. Tables 7 and 8 contain the Sludge and Varnish Ratings Summaries, respectively. An examination of the data in Tables 7 and 8 reveals that all the test lubricants performed satisfactorily. Those sludge and varnish ratings that averaged below a rating of 8 were still average or above as compared to ratings normally achieved by other oils in fleet tests. The results averaging 8 or higher are considered to be indicative of very good performances by the test oils. Table 9 gives a brief summary of the maintenance histories for each test engine. Normal maintenance consisted of routine scheduled maintenance and replacement or repairs due to normal wear and tear. Specific maintenance actions were noted where the problems could possibly have been oil related. However, no positive conclusions can be made about the actual impact any given test oil had on any given engine.

TABLE 7. SLUDGE RATINGS SUMMARY FOR TEARDOWN ENGINES
(10 = Clean)

	Type Oil					
Installations	Green	Yellow	Blue			
			A	B	C	D
AF Academy	9.6	9.7			9.6	
George*	9.8	9.8			9.8	
Grand Forks, ND		9.6		9.5		
Hancock**	No sludge ratings					
Lackland	9.4	9.6	9.7			
Minot	9.7				9.6	
Myrtle Beach	9.3	9.2				9.5
Offutt	8.4			6.7		
Peterson	9.7	8.6			9.6	
Randolph	9.7	9.6	9.4			
Average	9.5	9.4	9.6	8.1	9.7	9.5

* These ratings are for the left and right valve decks and pushrod chamber only; the rocker arm covers, oil pan and intake manifolds were missing from the engines when received at AFLRL.

**The parts that are rated for sludge deposits were missing from the engines when received at AFLRL.

TABLE 8. VARNISH RATINGS SUMMARY FOR TEARDOWN ENGINES
(10 = Clean)

	Type Oil					
Installations	Green	Yellow	Blue			
			A	B	C	D
AF Academy	7.3	7.5			8.7	
George	7.0	7.8			7.4	
Grand Forks, ND		9.6		9.5		
Hancock	6.0	9.95				
Lackland	8.8	8.2	7.4			
Minot	7.8				8.6	
Myrtle Beach	6.0	5.8				5.7
Offutt	6.1			5.8		
Peterson	8.8	7.7			6.7	
Randolph	8.9	9.6	9.4			
Average	7.4	8.3	8.4	7.7	7.9	5.7

TABLE 9. MAINTENANCE HISTORY FOR TEARDOWN ENGINES

MAJCOM	Installation	Vehicle No.	Color Code	Maintenance Actions
	USAFA, CO	79B5659	Green	Normal maintenance
		79B5660	Yellow	Normal maintenance
		79B5668	Green	Normal maintenance
TAC	GAFB, CA	79B2533	Green	Normal maintenance
		79B2534	Yellow	Normal maintenance
		79B2539	Blue(C)	Normal maintenance
SAC	GFAFB, ND	79B1734	Yellow	Right valve cover gasket leaking. Left valve cover leaking. Constant system problems.
		79B1735	Blue(B)	Oil leaks top and bottom of engine valve job rod bearings. Replaced #8 piston.
	HAFB, NY	78B5038	Green	Normal maintenance
		78B5646	Yellow	Replaced head and head gasket (added 1 qt. Quaker State by mistake @ 12,206 mi. Head gasket blew @ 12,218 mi.)
ATC	LAFB, TX	79B2270	Yellow	Normal maintenance
		79B2271	Green	JOAP remarked that this engine "was one of the worst vehicles in the Synlube program with respect to wear"
		79B2272	Blue(C)	Normal maintenance
	MAFB, ND	79B1736	Green	Engine had quit at end of test and had been partially dismantled.
		79B1759	Blue(C)	Normal maintenance
	MBAFB, SC	79B5212	Green	Normal maintenance
		79B9187	Yellow	Valve cover leak @ about 49,000 mi.
		79B9188	Blue(D)	Normal maintenance
SAC	OAFB, NE	78B4766	Green	Valve noise @ 30,753 mi. Knock in engine @ 44,168 mi. Engine cuts out and stalls @ 49,194 mi. Oil leak at valve @ 51,042 mi.
		78B4768	Blue(C)	Normal maintenance
ADCOM	PAFB, CO	78B4569	Green	Normal maintenance
		78B4571*	Yellow	Push rods, valves, lifters, camshaft and eventually, the entire engine was replaced(4).
		78B8831	Blue(C)	Normal maintenance

*A study of this engine was made by Air Force personnel and the conclusion was reached that the problems were attributable to a faulty air induction system (4)

TABLE 9. MAINTENANCE HISTORY FOR TEARDOWN ENGINES
(Cont'd)

MAJCOM	Installation	Vehicle No.	Color Code	Maintenance Actions
	RAFB, TX	79B5719	Yellow	Normal maintenance
		79B5720	Blue(A)	Normal maintenance
		79B5721	Green	Normal maintenance

Examinations of the engines after being disassembled did not reveal any significant differences between the problem engines and the others in the test. The difficulties could well have been attributed to maintenance practices and procedures. Appendix B, Volume II, shows the wear measurements for each of the test engines while Table 10 gives a summary of the wear measurements data for each engine and indicates those components worn beyond the manufacturer's specifications. A tabulation of the results reveal that of 79 wear measurements outside of manufacturer's specified wear limits, 27 percent of them were from engines operated on a Blue oil, 35 percent of them were from engines operated with the Green lubricant and 38 percent of them were from engines operated with the Yellow lubricant. This indicates that the engines operated with the synthetic oils experienced a higher wear rate than those operated with the normal issue mineral oils. The largest single category of wear measurements outside of specifications for all of the teardown engines was compression ring gaps, top and bottom. Other wear measurements outside of manufacturer's specifications appeared to be normal for the mileage and usage of each engine. With the exception of Hancock AFB which showed a significant difference in the average oil change mileage between its two engines, the average oil change interval in miles for each set of engines tended to group by installation. Assuming the information valid and the maintenance data for each vehicle seems to confirm it solidly, this would indicate a difference primarily in the basic maintenance procedures and practices at each installation. It should be noted that there were no oil changes at all for the three engines from Randolph AFB, nor the engine operated with Green oil at the USAF Academy which ended up with a total of 28,409 test miles. Table 11 shows the average oil change intervals for all test engines at each installation. Nine of the ten installations shown

TABLE 10. ENGINE INSPECTION DATA-WEAR MEASUREMENTS SUMMARY*

Type Engine	Ford, 6 cyl, 200 CID			Dodge V-8, 318 CID		
Installation	US Air Force Academy			George AFB		
Vehicle No.	79B5659	79B5660	79B5668	79B2533	79B2534	79B2539
Type Oil	Green	Yellow	Blue (C)	Green	Yellow	Blue (C)
Overall Average Measurements						
Compression Ring Gaps						
Top	0.029 a/(0.74)	0.027 a/(0.69)	0.028 a/(0.71)	0.028 a/(0.64)	0.026 a/(0.66)	0.025 a/(0.64)
Bottom	0.027 a/(0.69)	0.026 a/(0.66)	0.026 a/(0.66)	0.027 a/(0.69)	0.026 a/(0.66)	0.026 a/(0.66)
Cylinder Bore to Piston Clearances	0.0016 (0.041)	0.0023 a/(0.058)	0.0024 a/(0.061)	0.0012 (0.030)	0.0003 a/(0.008)	0.0011 (0.028)
Main Bearing Journal to Bearing Shell Clearances	0.0202 a/(0.513)	0.0022 (0.056)	0.0201 a/(0.511)	0.0012 (0.030)	0.007 a/(0.178)	0.0021 (0.053)
Connecting Rod Journal to Bearing Shell Clearances	0.0034 a/(0.086)	0.0037 a/(0.094)	0.0026 (0.066)	0.0018 (0.046)	0.0021 (0.053)	0.0026 a/(0.066)
Valve Stem to Guide Clearances	0.0014 (0.036)	0.0019 (0.048)	0.0015 (0.038)	0.0017 (0.043)	0.0014 (0.036)	0.0020 (0.51)
Valve Spring Compression, psi (N-m)	54.4 (242)	54.9 (244)	54.8 (244)	84.4 (375)	84.6 (376)	84.4 (375)
Camshaft Lobe Lift	0.229 a/(5.82)	0.242 (6.15)	0.244 (6.20)	0.246 a/(6.25)	0.244 a/(6.20)	0.243 a/(6.17)

* = Average wear measurements for each component are in inches and (mm) except valve spring compression.
a/ = Outside manufacturer's specifications for maximum wear limits.

TABLE 10. ENGINE INSPECTION DATA-WEAR MEASUREMENTS SUMMARY (CONT'D)

Type Engine	Chevrolet V-8, 350 CID				Ford, 6 cyl, 300 CID			
Installation	Grand Forks AFB		Minot AFB		Lackland AFB			Hancock AFB
Vehicle No.	79B1734	79B1735	79B1736	79B1759	79B2271	79B2270	79B2272	79B5646
Type Oil	Yellow	Blue (B)	Green	Blue (C)	Green	Yellow	Blue (A)	Yellow
Overall Average Measurements								
Compression Ring Gaps								
Top	0.025 (0.64)	0.024 (0.61)	0.023 b/ (0.58)	0.030 (0.76)	0.067 a/ (1.70)	0.044 a/ (1.12)	0.031 a/ (0.79)	0.026 a/ (0.66)
Bottom	0.024 (0.61)	0.026 (0.66)	0.024 (0.61)	0.027 (0.69)	0.064 a/ (1.63)	0.041 a/ (1.04)	0.031 a/ (0.79)	0.026 a/ (0.66)
Cylinder Bore to Piston Clearances	0.0023 (0.058)	0.0025 (0.064)	0.0020 (0.051)	0.0021 (0.053)	0.0030 a/ (0.076)	0.0022 (0.056)	0.0028 a/ (0.071)	0.0024 a/ (0.061)
Main Bearing Journal to Bearing Shell Clearances	0.0036 a/ (0.091)	0.0018 (0.046)	0.0027 (0.069)	0.0031 (0.079)	0.0023 (0.058)	0.0023 (0.058)	0.0024 (0.061)	0.0034 a/ (0.086)
Connecting Rod Journal to Bearing Shell Clearances	0.0030 (0.076)	0.0029 (0.074)	0.0033 a/ (0.084)	0.0024 (0.061)	0.0029 a/ (0.074)	0.0026 a/ (0.066)	0.0023 (0.058)	0.0045 a/ (0.114)
Valve Stem to Guide Clearances	0.0015 (0.038)	0.0015 (0.038)	0.0014 (0.036)	0.0018 (0.046)	0.0021 (0.053)	0.0017 (0.043)	0.0015 (0.038)	d/
Valve Spring Compression, psi (N-m)	76.9 (342)	75.4 (335)	75.1 (334)	72.4 (322)	79.5 (354)	79.4 (353)	79.5 (354)	d/
Camshaft Lobe Lift	0.265 a/ (6.73)	0.265 a/ (6.73)	0.265 a/ (6.73)	0.253 a/ (6.43)	0.245 (6.22)	0.247 (6.27)	c/	0.233 a/ (5.91)

b/ = No Rings on Pistons 6 and 8
c/ = Camshaft lobe diameters were measured instead of lobe lift; measurements were within manufacturer's specifications
d/ = No head with engine when uncrated

TABLE 10. ENGINE INSPECTION DATA-WEAR MEASUREMENTS SUMMARY (CONT'D)

Type Engine	Dodge, 6-Cyl, 225 CID			
Installation	Hancock AFB	Myrtle Beach S.C.		
Vehicle No.	79B5038	79B5212	78B9187	78B9188
Type Oil	Green	Green	Yellow	Blue (D)
Overall Average Measurements				
Compression Ring Gaps				
Top	0.046 (1.17)	0.097 a/ (2.46)	0.10 a/ (2.54)	0.029 (0.74)
Bottom	0.034 (0.86)	0.065 a/ (1.65)	0.078 a/ (1.98)	0.028 (0.71)
Cylinder Bore to Piston Clearances	0.0017 a/ (0.043)	0.0028 a/ (0.071)	0.0026 a/ (0.066)	0.0015 (0.038)
Main Bearing Journal Bearing Shell Clearances	0.0016 (0.041)	0.0030 a/ (0.076)	0.0029 a/ (0.074)	0.0016 (0.041)
Connecting Rod Journal to Bearing Shell Clearances	0.0105 a/ (0.267)	0.0037 a/ (0.094)	0.0040 a/ (0.102)	0.0262 a/ (0.665)
Valve Stem to Guide Clearances	d/	0.0020 (0.051)	0.0032 (0.081)	0.0021 (0.053)
Valve Spring Compression, psi (N-m)	d/	51.2 (228)	51.2 (228)	140.3 (624)
Camshaft Lobe Lift	0.264 a/ (6.71)	0.270 a/ (6.81)	0.268 a/ (6.93)	0.273 a/ (6.83)

TABLE 10. ENGINE INSPECTION DATA-WEAR MEASUREMENTS SUMMARY (CONT'D)

Type Engine	Chevrolet, 6 Cyl, 292 CID					Ford, 4 Cyl, 140 CID		
Installation	Offutt AFB		Peterson Field			Randolph AFB		
Vehicle No.	78B4766	78B4768	78B4569	78B4571	78B8831	79B5721	79B5719	79B5720
Type Oil	Green	Blue (B)	Green	Yellow	Blue (C)	Green	Yellow	Blue (A)
Measurements								
Compression Ring Gaps								
Top	0.030 (0.76)	0.029 (0.74)	0.023 (0.58)	0.024 (0.61)	0.025 (0.64)	0.026 a/(0.66)	0.029 a/(0.74)	0.025 a/(0.64)
Bottom	0.029 (0.74)	0.031 (0.79)	0.026 (0.66)	0.030 (0.76)	0.026 (0.66)	0.029 a/(0.74)	0.029 a/(0.74)	0.025 a/(0.64)
Cylinder Bore to Piston Clearances	0.0041 a/(0.104)	0.0039 a/(0.99)	0.0038 a/(0.097)	0.0043 a/(0.109)	0.0040 a/(0.102)	0.0015 (0.030)	0.0017 (0.041)	0.0011 (0.023)
Main Bearing Journal to Bearing Shell Clearances	0.0032 (0.081)	0.0029 (0.074)	0.0024 (0.061)	0.0022 (0.056)	0.0029 (0.074)	e/	e/	e/
Connecting Rod Journal to Bearing Shell Clearances	0.0027 (0.069)	0.0087 a/(0.221)	0.0041 a/(0.104)	0.0108 a/(0.274)	0.0037 a/(0.094)	e/	e/	e/
Valve Stem to Guide Clearances	0.0014 (0.036)	0.0016 (0.041)	0.0029 (0.074)	0.0015 (0.038)	0.0028 (0.071)	e/	e/	e/
Valve Spring Compression, psi (N-m)	172.3 (766)	170.3 (758)	81.3 (362)	171.3 (762)	80.3 (357)	e/	e/	e/
Camshaft Lobe Lift	0.220 (5.59)	0.218 (5.54)	e/	0.224 (5.69)	0.221 (5.61)	0.242 (6.15)	0.242 (6.15)	0.243 (6.17)

e/ = Only representative measurements made when visual inspection revealed no abnormal appearances; representative measurements within manufacturer's specifications for new engine.

TABLE 11. AVERAGE OIL CHANGE INTERVALS AT EACH INSTALLATION

Installation	Average Oil Change Intervals, miles
USAD Academy	16,040.8
George AFB	4,161.9
Grand Forks AFB	4,212.9
Hancock AFB	5,773.2
Lackland AFB	2,923.1
Minot AFB	7,535.1
Myrtle Beach AFB	11,185.9
Offutt AFB	6,874.5
Peterson AFB	4,380.9
Randolph AFB	10,052.7

average over 4,000 miles between oil changes, and six of those nine average above 5,000 miles between oil changes, while three of the nine average over 10,000 miles between oil changes. Photographs of selected engine components are exhibited in Appendix C, Volume II. Although no conclusive inferences may be made from the appearance of photographed components, the components from engines operated with the Yellow lubricants appeared slightly cleaner, overall, than the components from engines operated with the Blue and Green lubricants.

Performance Summary

As stated earlier, all the test oils appeared to have performed satisfactorily. Table 12 assigns a subjective performance rating in each of the categories listed for each oil with respect to used oil condition and the engine inspection data.

Combining these ratings, the test oils are ranked in the following order of overall performance:

TABLE 12. OVERALL PERFORMANCE RATINGS*

	Blue	Green	Yellow
Sludge Ratings	Good	Best	Better
Varnish Ratings	Better	Good	Best
Other Ratings	Best	Good	Better
Wear Measurements	Best	Better	Good
Total Particulate Contaminants	Best	Better	Good
Average VDP vs. True Value VDP	Best	Good	Better
Oil Dispersive Properties	Best	Better	Good

1. Blue - The normally issued mineral oils (collectively) performed in a satisfactory manner and although between the Green and Yellow oils in sludge, varnish and other ratings were judged to be demonstrably better than the two multiviscosity synthetic oils in wear measurements, particulate contaminants, viscosity increase, and dispersive properties.

2. Green and Yellow - Both multiviscosity synthetic oils performed satisfactorily and equally well overall with respect to each other. The Yellow oil performed better than the Green and Blue oils in the ratings, but not as well as the other two with respect to wear measurements, particulate contaminants, viscosity increase, and dispersive properties.

IV. CONCLUSIONS

- The Blue lubricants (collectively) demonstrated the best overall performance of the test oils used.
- The Green and Yellow lubricants performed equally well overall and can be satisfactorily used in spark ignition engines of the type tested.
- Engine distress evidenced by light to severe piston scuffing and cracked, chipped, scuffed, and worn lifter bodies for the Chevrolet 350 V8 engines and cracked, chipped, and worn lifter bodies for the

Chevrolet 6-cylinder 292 engines cannot be attributed exclusively to the lubricants used since the distress occurred in the engines regardless of the type test oil used.

- Components of the engines operated with the Green and Yellow lubricants exceeded manufacturer's wear limit specifications more frequently than those from engines operated with the Blue oils.

V. RECOMMENDATIONS

Based on the observations and conclusions drawn from the teardown inspections and analysis of information provided for the twenty-six engines only, the following recommendations are made:

- Conduct a test at the following bases to determine the contribution of climatic and environmental conditions to the engine distress exhibited by the Chevrolet engines utilized:

  Minot Air Force Base, ND
  Grand Forks Air Force Base, ND
  Offutt Air Force Base, NE
  Peterson Field, CO

- Consideration be given to future cooperative tests of this type for obtaining lubricant field data.

VI. REFERENCES

1. Letter, Department of the Air Force, Headquarters Warner Robins Air Logistics Center (AFLC), Robins Air Force Base, Georgia 31098, Attn: MMEAP (Mr. Coffey/2711) to U.S. Army Fuels & Lubricants Research Laboratory, San Antonio, TX 78284, Subject: MEEP Project H79-1C, Synthetic Oils, dated 22 January 1979.

2. Final Report on Field Liaison in Support of Evaluation of Synthetic Lubricants in Nontactical Vehicles, Contract No. F33615-79-C-5159 by Anna F. Stulsas and John D. Tosh, Energy Systems Research Division, Southwest Research Institute, San Antonio, TX 78284, dated February 1982.

3. Note, Technical Support Center, Joint Oil Analysis Program, Building 780, Naval Air Station, Pensacola, Florida 32508, Attn: SMS Ed Stembler, to Walt Butler (USAFLRL), Subject: Baseline Data for Lubricants Used in the SYNLUBE project, dated 25 January 1982.

4. Letter, Technical Support Center Joint Oil Analysis Program, Building 780, Naval Air Station, Pensacola, Florida 32508, Attn: JOAP-TSC, to Southwest Research Institute, Mobile Energy Division, Attn: Mr. John D. Tosh, 6220 Culebra Road, San Antonio, TX 78284, Subject: SYNLUBE Data Format w/Enclosure (1), dated 25 September 1981.

5. Maintenance Record accompanying Engine 78B4571.

6. Military Specification, MIL-L-46152, "Lubricating Oil, Internal Combustion Engine, Administrative Service," dated 20 November 1970.

7. CRC Manual No. 8, "CRC Varnish Rating Manual for Non-Rubbing Parts," dated March 1964.

8. CRC Manual No. 9, "CRC Varnish Rating Manual," dated June 1971.

9. CRC Manual No. 10, "Sludge Rating Manual," dated May 1966, revised January 1969.

10. CRC Manual No. 4, " Techniques for Valve Rating," Table 12, dated January 1958, revised July 1969.

LIST OF ACRONYMS

ADCOM	-	Aerospace Defense Command
AFLC	-	Warner Robins Air Logistic's Center
AFSC	-	Air Force Systems Command
ATC	-	Air Training Command
CID	-	Cubic Inch Displacement
CRC	-	Coordinating Research Council
DOD	-	Department of Defense
GAFB	-	Georgia Air Force Base
GFAFB	-	Grand Forks Air Force Base
HAFB	-	Hancock Air Force Base
JDLC	-	Joint Deputies for Laboratory Committee
JOAP	-	Joint Oil Analysis Program
LAFB	-	Lackland Air Force Base
MAFB	-	Minot Air Force Base
MAJCOM	-	Major Command
MBAFB	-	Myrtle Beach Air Force Base
MEEP	-	Management Equipment Evaluation Program
OAFB	-	Offutt Air Force Base
PAFB	-	Peterson Air Force Base
RAFB	-	Randolph Air Force Base
SAC	-	Strategic Air Command
SwRI	-	Southwest Research Institute
Synlube	-	Synthetic Lubricant
TAC	-	Tactical Air Command
TAN	-	Total Acid Number
TBN	-	Total Base Number
TSC	-	Technical Support Center
USAFA	-	United States Air Force Academy
USAFLRL	-	United States Army Fuels & Lubricants Research Laboratory
Belvoir R&D Center	-	U.S. Army Belvoir Research & Development Center
VDP	-	Viscosity Density Product

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NEW CUMBERLAND PA 17070

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PENSACOLA FL 32508

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MAT-08E (MR ZIEM) 1
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